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RESEARCH PAPER

Interactive Method for Supporting Forest Owners in Biodiversity Protection Decisions

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Abstract Voluntary biodiversity protection tools have been adopted for practical use in many countries where non-industrial private forest ownership includes invaluable biodiversity resources. This has created a new kind of decision problem for individual forest owners: they should be able to define their conditions for entering into a biodiversity protection contract including sometimes a predetermined subsidy. This study presents a holding-level method for examining this decision problem. The method is based on utilization of interactive optimization where the possible subsidy has been included in the protection (no treatment) alternative of the examined stand. Generally, interactive optimization means that the landowner pinpoints the best plan by interactively studying and learning the production possibilities of his/her forest holding. Following changes made to the objective function by the forest owner, new solutions are presented for forest owners' evaluation. If the "No treatments" option is selected in optimization for these areas, the forest owner would benefit more—in the current location of the production frontier and with the current subsidy—from entering into the protection contract than from cutting the specific forest area. In the case study, we demonstrate that the values of the holding-level goals, production possibilities of the planning area and the levels of the subsidy have a significant effect on the optimal decisions relating to biodiversity protection on the stand level.

Keywords Biodiversity protection · Forest planning · Non-industrial private forestry · Interactive planning · Optimization

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Introduction

Voluntary protection of biodiversity has been adopted in practice in many countries where non-industrial private forests include invaluable biodiversity resources. The voluntary protection of biodiversity here means that, opposite to previous top–down based protection programs, the forest owner makes the final decision whether to participate or not to the established biodiversity protection project. For example, the Austrian Forest Reserves Programme was launched in 1995 (Frank and Müller 2003); various voluntary incentive programs have been offered for non-industrial private forest owners in the United States (e.g., USFWS (Fish and Wildlife Service) 1998); and several new instruments focusing strongly on non-industrial private forests were introduced and tested recently in Finland in the so-called METSO-programme (Etelä-Suomen, Oulun läänin länsiosan… 2002).

The said METSO programme tested new instruments such as competitive tendering, natural-values trading, and cooperative network projects on forest biodiversity in several pilot projects. These projects were located in different parts of Finland and they had different protection goals (e.g., Syrjänen et al. 2006; Kolström et al. 2006). A common characteristic of the new instruments was that forest owners can offer parts of their forest areas for permanent or temporary protection (mainly natural-values trading). Furthermore, the suitability of the areas offered for protection was evaluated by using common criteria (Etelä-Suomen metsien… 2003) that were created specifically for the needs of this program (Etelä-Suomen, Oulun läänin länsiosan … 2002).

The experiences gained during the Finnish testing period were mainly positive (Kolström et al. 2006), particularly the freedom to decide upon participation, retaining the ownership of the protected forest area and related to this, the rather short 10-year protection periods, were valued by the forest owners (e.g., Syrjänen et al. 2006). From the society's point of view, two drawbacks associated with voluntary protection tools may, however, be seen in that it is not possible to select the best protection area network based purely on the ecological properties of the forests, or that the costs of the protection area network become higher than in the case of expropriation, e.g., due to costs caused by continuous negotiation processes and inventories of the forest areas (e.g., Juutinen et al. 2008). On the other hand, the social acceptability of voluntary tools may be higher than in the case of using conventional protection tools, which have been traditionally based on environmental legislation and resulting authority-driven top–down approaches. If voluntary protection tools result in a decreased number of conflicts, it is also possible for positive economic impacts to occur. Furthermore, incentives promoting the formation of ecologically desirable networks of protection areas can be formulated for voluntary biodiversity protection (Parkhurst et al. 2002).

Voluntary protection of biodiversity is characterized by a subsidy being paid to the landowner when he/she decides to protect biodiversity within a certain forest area. Depending on the formulation and the terms and conditions of the biodiversity protection instrument, the level of the subsidy can be defined only by the buyer (e.g., the central government or local authorities involved in biodiversity protection). Alternatively, the level of the subsidy can be the result of negotiations or price

bargaining between the buyer and the seller (e.g., a non-industrial private forest owner). In both of these cases, the forest owner needs to determine whether he/she benefits more from using the forest area in question for conventional forestry purposes or from entering into a biodiversity protection contract involving a specific subsidy (monetary compensation fee). In the new (second) METSO program (Etelä-Suomen metsien…2008), it seems that the subsidy will be defined by the buyers, i.e., local forestry or environmental authorities and the negotiation and price bargaining are not needed.

In commercially managed boreal forests, the conventional forest management usually means clear-cutting the forest areas at the end of the rotation period which varies between 60 and 120 years (e.g., Hyvän metsänhoidon suositukset 2006). In addition to the characteristics of the forest area, e.g., the characteristics of an individual forest stand from the viewpoint of timber production and biodiversity protection, the forest owner’s forest management goals and the production possibilities of the entire forest holding are affecting this decision (e.g., Kurttila et al. 2006, 2008). In some cases, the forest owner might be willing to protect their forest areas with a subsidy that is lower than the market price based compensation (e.g., Juutinen et al. 2008).

Voluntary biodiversity protection programs are still novel tools in many countries. This is why the associated decision-support methods are relatively rare. Kurttila et al. (2006), however, presented and tested (Kurttila et al. 2008) an application of the multi-attribute utility theory for defining the holding-level opportunity cost for a biodiversity protection contract. The method results in a opportunity cost level, which, together with treatments selected for other stands of the holding, produces total utility that is equal than in a case where the examined forest stand is regenerated during the planning period. The opportunity cost is sought iteratively in the method. When compared to the interactive method presented in this study, the search for the minimum price level is technically more effective, i.e., it finds exactly the opportunity cost that corresponds to reduced production possibilities. On the other hand, the method calls for the forest owner’s explicit and accurate utility function, which is not always available.

The characteristics of holding-level forest planning correspond also to the characteristics of planning for voluntary and temporal biodiversity protection; protection contracts are typically made for 10–20 years time periods, the protection area typically covers an individual forest stand and the protection decision is derived from the owner’s holding-level goals. Hence, biodiversity protection could rather straightforwardly be included in holding-level planning calculations (e.g., Kurttila et al. 2006, 2008).

The goal of this study is to introduce an interactive method for supporting forest owners in biodiversity protection decisions. The method helps the forest owners in examining the effects of his/her preferences and the possibly predefined subsidy level on the contents of the holding-level forest plan as well as the optimal treatment of the specific ecologically valuable forest stands within the holding. In principle, the method is suitable for cases where the subsidy is defined by the buyer of biodiversity protection, by the forest owner, or by negotiation or bargaining between the buyer and the forest owner. Chapter 2 introduces the planning method on

general level, and the Chapter 3 introduces a specific application of the method. In this application, interactive heuristic optimization is used in connection with a planning case area from eastern Finland. This is followed by a discussion of the pros and cons of the method.

Planning Method

Tactical Forest Planning and Interactive Optimization

Tactical forest planning produces a treatment proposal for each individual forest stand so that the goals set for forest management on the level of the entire forest holding are met in the best possible way. This is often a very complex decision problem due to several and often competing goals. Furthermore, the amount of alternative plans is typically very large. For example, about one million different forest plans can be produced for a forest holding having 20 forest stands and each of these stands having two alternative treatments schedules. Hence, it is evident that including forest owner's holding level goals genuinely in planning calculations without use of efficient methods and tools is a very difficult and time consuming task.

Due to complexity of tactical level forest planning problems, different planning models and optimization algorithms for solving these models have been developed (e.g., Kangas et al. 2008). The planning model includes (a) the alternative treatment schedules for individual forest stands, and (b) the forest owner's goals (e.g., Pukkala 2008). When constructing planning models, the effects of alternative treatment schedules defined for individual stands are estimated by computer simulations, and the forest owner's goals for forest management are defined in the form required by the planning system. Most often this means formulating the goals to a form of mathematical programming (e.g., standard linear programming or goal programming) problem or to a form of utility/value function. The solution of the planning model optimally integrates the forest owner's forest management goals and the production possibilities of the planning area.

The use of the above defined planning models includes several benefits. According to Pukkala (2008) the quantitative analysis are efficient, quick, cheap, objective and repeatable. However, in practical planning an adequate planning model cannot be formulated on the first trial because (i) the forest owner's goals in forest management may be fuzzy to him/her, or (ii) he/she may not know well enough the production possibilities of the forest area under planning before the planning session, or (iii) the planning method is difficult to use and understand, and (iv) formulating the objective function so that it results in an acceptable plan takes too much time (see also Pykäläinen 2000b). Interactive forest planning is an approach for tackling these difficulties when technical objective models and methods are used in practical planning cases (Pykäläinen 2000b). Furthermore, interactive planning, as such, obviously corresponds to some forest owners' preferred way of grasping and processing information (this is a matter of learning styles, see Kolb 1984).

The basic idea behind interactive optimization is that learning about the interconnections between various goals and their substitutability in different decision alternatives helps the decision maker to make wise decisions (e.g., Steuer 1986). In interactive optimization, the solution is gradually improved by alternating the steps of defining and solving the planning model, until the decision maker is satisfied with the result (e.g., Steuer 1986).

In forest planning, interactive optimization means that the landowner finds the best plan—which consists of the optimal combination of alternative treatment schedules of individual forest stands—by interactively studying the efficient production possibilities of the forest holding (e.g., Steuer 1978; Steuer and Schuler 1981; Harrison and Rosenthal 1988; Pukkala 1988; Pykäläinen 2000b). Instead of defining the goals for forest management before the planning calculations, the forest owner actually learns his/her goals or target levels during the planning session. The forest owner's goals in forest management are an important output of the interactive planning process.

Depending on the planning model, interactive optimization can be technically carried out by, for example, altering the weights (e.g., Pykäläinen 2000a, 2000b) or the target levels (e.g., Mykkänen 1994) of individual goals and by solving the corresponding optimization problems. After each change, the solution is presented for the forest owner to evaluate. In this process, the forest owner decides whether the current solution needs to be changed and what kind of a change would be desirable. Deciding about the overall optimum among the alternative solutions is the forest owner's task.

Planning Process

When supporting forest owners in biodiversity protection decisions the planning problem is to find out whether it would be a rational decision for the forest owner to make a voluntary biodiversity protection contract when taking into account (a) the forest owner's goals for forest management, (b) the production possibilities of the planning area and (c) the offered subsidy level.

The steps of the planning process in this kind of situation are as follows:

- Step 1. The forest inventory data is entered into the planning system.
- Step 2. The planning model including the alternative treatment schedules for individual stands and the forest owner's holding-level objectives is defined. The subsidy for voluntary protection of biodiversity is added to the "No treatment" alternative of the examined forest stand and it is treated similarly as cutting income. "No treatments" alternative means that these areas are in practice set aside for the period that equals the length of the planning calculations. Active management of these areas, i.e., restoration, is not considered in this study.
- Step 3. The planning model is solved and the forest owner evaluates the solution. Feedback concerning the values of holding-level goals and the treatment schedule selected for the potential biodiversity protection area(s) is presented to the forest owner. If the "No treatments" option is selected for

the potential protection area, the forest owner would benefit more—in the current location of the production frontier and with the current level of the subsidy—by entering in a protection contract for the potential area of biodiversity protection than he would by cutting the forest area in question. If the forest wants to improve the solution or he/she wants to return to a solution produced earlier, the process is repeated beginning from the Step 2. If he/she thinks the best plan had been found out, the process proceeds to the Step 4.

Step 4. The forest plan document is produced.

Case Study

Planning Area

A typical non-industrial private forest holding from eastern Finland was selected for the case study area. The total area of the forest holding under planning is 32.8 ha, which includes 20.1 ha of forestland. The main tree species are pine, spruce and birch (Table 1). Middle-aged and mature stands are the most common within the planning area (Table 2).

There were 23 forest compartments in the planning area. Two of these compartments (#17 and #18) could be suitable for biodiversity protection. The area of compartment #17 is 1.4 ha, its total volume is 235 m^3/ha and its annual value growth is € 138/ha. The stand consists of one canopy layer of pine, two canopy layers of spruce and two canopy layers of birch. The area of compartment #18 is 1.1 ha, and the stand consists of 200 m^3/ha of old spruce (age 130 years) and 70 m^3/ha of middle-aged pine (age 60 years). The annual value growth is € 92/ha. Some of the standing trees are dead and there is also some deadwood on the ground, which makes the stands valuable for several species that demand large-diameter dead-trees (e.g., Tikkanen and Kouki 2007). In addition, the within stand conditions remain

Table 1 Total volumes of different tree species in the case study holding

Species	Volume, m^3	Sawlogs, m^3	Pulpwood, m^3
Pinus sylvestris	2,589	1,043	1,379
Picea abies	477	308	157
Betula pendula	151	3	88
Betula pubescens	191	12	113
Populus tremula	14	2	10
Alnus incana	157	0	92
Sorbus aucuparia	2	1	1
Salix sp.	30	0	0
Total	3,612	1,369	1,839

Table 2 The areas and the total wood volumes in different development stages in the case study holding

Development stage	Area, ha	Volume, m^3
Seedling stands	1.6	99
Sapling stands	2.3	171
Pole-stage stand	2.5	154
Middle-aged stands	8.2	1,829
Mature stands	5.6	1,360
Total	20.1	3,612

suitable for these species and ultimately, as trees become older, the amount of dead wood will increase.

Planning Model

Alternative Treatment Schedules for the Forest Stands

Alternative treatment schedules were simulated for each individual stand following the official Finnish forest management recommendations (Hyvän metsänhoidon suositukset 2006) for the forthcoming 10-year planning period. Both regeneration cuttings and "No treatments" alternatives were simulated for the stands #17 and #18 which were potential areas for voluntary protection of biodiversity, and the alternative subsidy levels were included in the "No treatments" alternatives of the examined stands.

Two different subsidy levels were included into the planning calculations of the case study so that the effects of the subsidy levels on the optimal solution could be illustrated. In the first case, the subsidy for the protection contract was € 167/ha/a for both stands. In the second case, the subsidy levels were € 84/ha/a for Stand #17 and € 167/ha/a for Stand #18. These levels of subsidy fall within the range paid to forest owners in the Finnish pilot project concerning the transactions focusing on sites having significant nature values (Gustafsson & Nummi 2004).

Objective Model

In this study, we used the HERO method (Pukkala and Kangas 1993) for defining the forest owner's objective model and solving it. The model adopts a form of additive utility function (Eq. 1), which consists of sub-utility functions defined separately for each goal variable and the weights of these variables.

$$U(q_1, q_2, \ldots, q_n) = \sum_{i=1}^{n} a_i u_i(q_i) \tag{1}$$

where

q_i is the amount of goal variable i expressed in its own units
$u_i(q_i)$ is the sub-utility function for goal i
a_i is the weight of goal i

Due to the interactive nature of planning, the forest owner does not have to define his/her utility function very precisely; the forest owner needs only to select the goal variables. Linear sub-utility functions and equal weights for the goals can be assumed in the starting point of interactive optimization.

In the case study, only two goal variables were used in the planning example to enable illustrations concerning the interconnections between the goal variables and the impacts of different levels of the subsidy. The method itself would not change if there were more goal variables. The used goal variables were the net present value of cutting income during the planning period and the total growing stock volume at the end of the planning period. The total growing stock volume at the end of the planning period measures possibilities to use forest after the planning period.

Interactive Optimization

The planning model was solved by applying the original direct-search algorithm of the HERO method (Pukkala and Kangas 1993). In large planning problems, or in planning problems that include spatial goals such as clustering of certain types of resources of cutting areas, alternative heuristic optimization algorithms (e.g., simulated annealing, tabu search, genetic algorithms or their variants) can be used for improving the quality of the solutions (Bettinger et al. 2002; Pukkala and Kurttila 2005; Kangas et al. 2008).

In the interactive optimization, the weights of the goal variables were alternated so that several solutions could be produced for evaluation. The sum of the weights was fixed to be one in the additive utility function of the planning model. The sub-utility functions for the goal variables were linear for the whole variation levels of the goal variable values. Very small iteration steps (increase/decrease of the weights of goals) were used to make it sure that the best combination of the goal variable values was found in interactive optimization.

The results of the interactive optimizations are presented in a form of efficient frontiers, i.e., production possibility boundaries. The efficient frontiers were calculated for the both subsidy levels (Fig. 1). In the first case, the subsidy for the protection contract was € 167/ha/a for both stands. In the second case, the subsidy levels were € 84/ha/a for Stand #17 and € 167/ha/a for Stand #18.

Adding the monetary subsidies to the "No treatment" alternatives of Stands #17 and #18 changes the location of the holding-level efficient frontier and also the selection of the treatment schedules for these compartments (Fig. 1). In both cases, it would not be wise for the forest owner to enter into a protection contract with the proposed subsidy levels if the holding-level cutting budget during the planning period is on a very high level (growing stock volume at the end of the planning period less than 2,500 m^3). On the contrary, very low cutting budgets (growing stock volume at the end of the planning period more than 3,750 m^3) would result in recommendation to protect both stands in both cases. When the growing stock volume at the end of the planning period is between 2,500 and 3,750 m^3, the different subsidy levels for Stands #17 and #18 resulted in different solutions on the level of the entire forest holding and of these two individual stands.

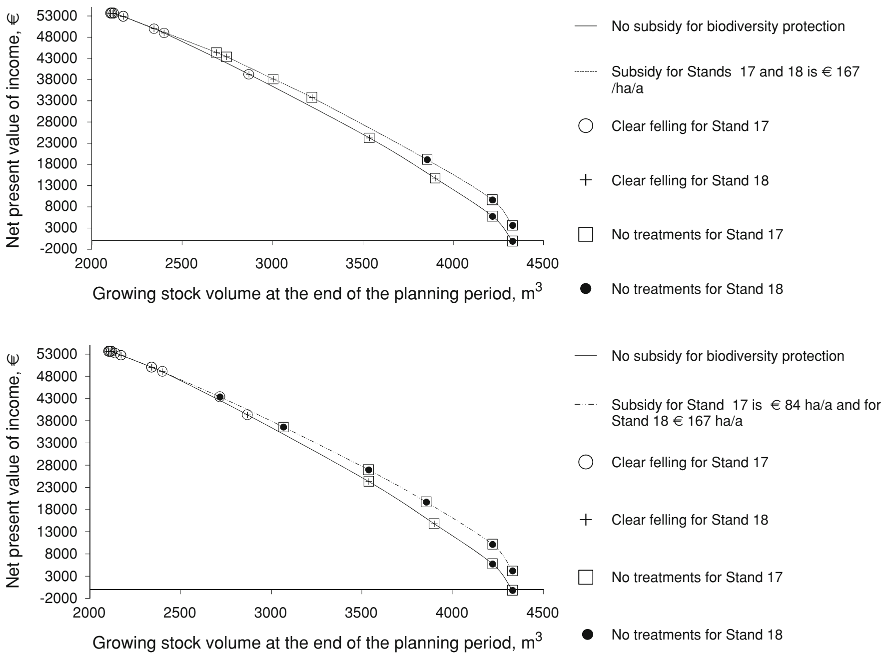

Fig. 1 The locations of the efficient forest plans and the treatment schedules selected for Stands #17 and #18 with two different levels of subsidy. In the upper figure, the subsidies are the same level (€ 167/ha/a) for both stands and in the lower figure the subsidy was € 84/ha/a for Stand #17 and € 167/ha/a for stand #18. Each mark on the efficient frontier corresponds to one holding-level plan. The treatment schedules of Stands #17 and #18 in the corresponding plan are marked by the symbols defined in the legend of the figure

Discussion

In principle, the results concerning the adoption or rejection of the protection contract with the predetermined subsidy levels and holding-level values of goal variables were valid only if all the factors having an impact on the forest owner's decision-making were included in the planning calculations. In addition, forest planning calculations always include uncertainty (e.g., Kangas et al. 2000), which can lead to adaptive behaviour on part of the forest owner when he implements the plan. As a result, the final plan and the subsidy levels connected to the protection contract are not necessarily optimal and "correct" in all cases.

Therefore, a forest plan produced using the method presented in this study should be considered as the "best guess" regarding the forthcoming treatments to be applied in the planning area. Hence, in spite of the general uncertainty of the planning calculations, it can be argued that the method offers new kind of holding-level decision support for the forest owner in biodiversity protection decisions. In addition, the forest owner's decisions can be supported by calculating the pure economic impacts of biodiversity protection on stand level (e.g., Kurttila et al. 2008). Learning the principles and results of both multi-objective holding-level

planning calculations and stand-level calculations probably helps the forest owner when making the final decisions. In addition, sensitivity analyses with respect e.g., changing management goals of the forest owner and/or different future timber prices can be done to improve these calculations.

A drawback of using interactive optimization in supporting biodiversity protection decisions is that mapping out the holding-level production possibilities and selecting the optimal one from among the efficient solutions must be done separately for each subsidy level. The amount of work depends on the process in which the level of the subsidy is defined. If the buyer, e.g., the central government or local authorities involved in biodiversity protection, defines the fee level, the owner uses this level in his own calculations and either accepts or rejects the offer. If the owner must himself/herself set the fee level, optimization calculations need to be repeated several times by applying alternative fees. If there are several fee levels resulting in both acceptable plans and biodiversity protection decisions, the choice between the fee levels in the forest owner's offer depends on the owner's attitude towards risk. Increasing the desired fee level also increases the probability that the forest owner's offer will be rejected on the biodiversity protection markets. Instead, it could be a wiser strategy to ask for a lower level of the fee, and still get a better solution through entering into a biodiversity protection contract than by cutting the potential area of biodiversity protection. In addition, in the case of negotiation and bargaining, the forest owner's decision process can be supported by implementing the optimization calculations with the different fee levels that the buyer is offering during the negotiation process.

The decision problem in this study can be tackled by many kinds of simulation-optimization systems. In interactive planning, however, genuine multi-objective techniques—i.e., techniques allowing several simultaneous goals—most often correspond to the forest owners' needs of learning about the production possibilities and the connections of different goals in his/her forest (e.g., Pykäläinen 2000b). Standard linear programming, for example, is not so suitable technique because the forest owner cannot necessarily state in advance which is the most important goal and which of the goals should be treated as constraints in the planning model. On the other hand, using a utility function as the planning model allows the forest owner to define his goals explicitly (if he is able and willing to do it) and by doing this he probably decreases the number of iterations needed for finding an acceptable plan and the corresponding subsidy level. The utility function—together with heuristic optimization algorithms—also allows one to use non-additive and spatial goal variables, which cannot be so easily integrated in the mathematical programming formulations.

In real planning cases, the forest owner must understand the method and feel that his/her forest management goals are really recognized and fulfilled in the final plan. In that sense, defining the planning model may be the most challenging task in the method presented in this study. However, in interactive planning the planning model does not have to be defined very accurately and the principles of optimization can be learned during the planning session. For example, Pykäläinen (2000a) tested an interactive planning process where the planning consultant first used thematic interview for clarifying the forest owner's general level goals, and after that, the

consultant—together with the forest owner—selected the goal variables for the optimization calculations, and the optimization calculations were carried out together with the forest owners. In that study, interactive approach for optimization was needed in the majority of the planning cases, the forest owners understood the principles of optimization quite well, and interactive optimization produced acceptable plans. Basically, including the option to take part in voluntary protection of biodiversity does not change the forest owner's manner of interacting with the planning consultant and the planning system, and thus it can be argued that the method presented in this study could be used also in practical planning.

The practical use of the method presented in this study call for a planning system in which defining and solving the planning model are flexible and quickly carried out. The result can be demonstrated to the forest owner in different ways. The most advanced tools of interactive planning include landscape visualizations, which allow one to immediately see the numeric and visual effects of the plan on the levels of both the entire forest landscape and individual stands (Pukkala 2000). No doubt, also the interpersonal interaction between the planning consultant and the forest owner will become more and more important in the future. Arranging interactive planning over Internet is an interesting topic for future research work.

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